As cold clouds warm, their lifetime increases: a negative feedback underestimated in GCMs

Johannes Mülmenstädt,[1] Sabine Hörnig,[1] Jennifer E. Kay,[2] Marc Salzmann,[1] Po-Lun Ma[3]

[1]Universität Leipzig [2]University of Colorado, Boulder [3]Pacific Northwest National Laboratory

3 October 2019

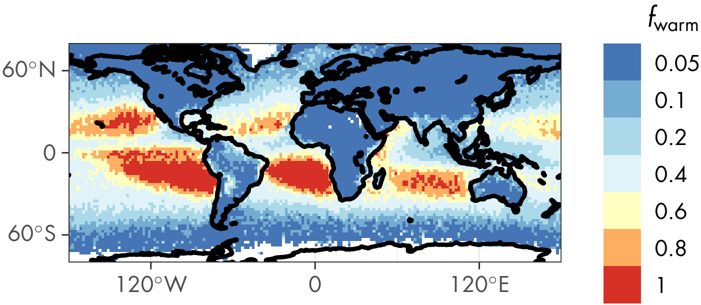
Midlatitude phase feedbacks: optics and lifetime

- Liquid clouds are more reflective than ice clouds: $\alpha(\mathcal{L} = x) > \alpha(\mathcal{I} = x)$
- Liquid clouds also live longer than ice clouds because warm precipitation is less efficient than cold precipitation
- GCMs overdo warm precipitation, so they underestimate the magnitude of the lifetime feedback

Aside slide

1. Feedback underestimate is the result of a base state bias
2. Use observations to reduce base state bias
3. Constrain using precipitation process variables rather than state variables

Rain from pure liquid clouds ("warm rain") is very rare over the extratropical continents

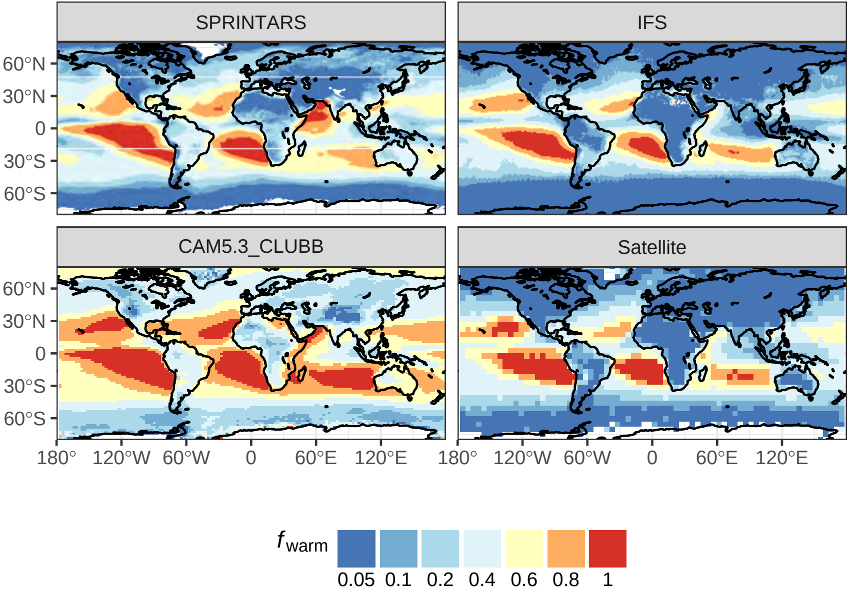


f_{warm} is the temporal fractional occurrence of warm rain, normalized by the occurrence of any type of rain, within a grid box at latitude ϕ and longitude λ:

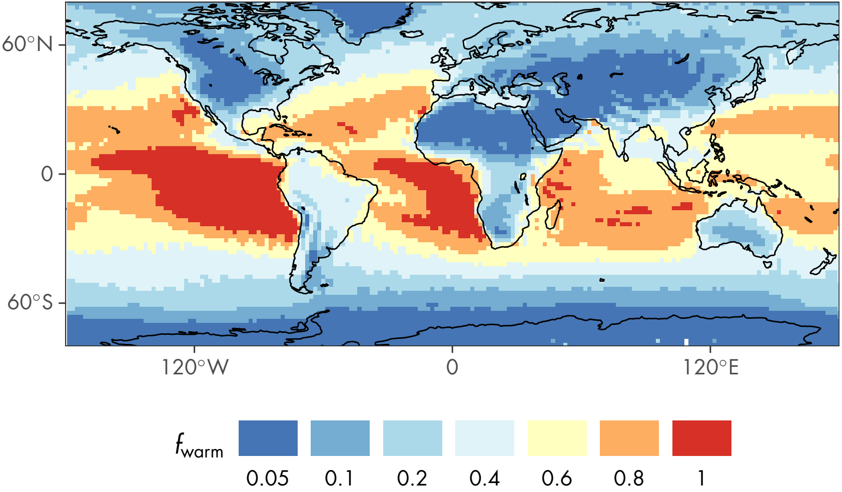
$$f_{\text{warm}}(\lambda, \phi) = \frac{n_{\text{warm rain}}(\lambda, \phi)}{n_{\text{warm rain}}(\lambda, \phi) + n_{\text{cold rain}}(\lambda, \phi)} \quad (1)$$

Mülmenstädt et al. (2015), *Geophys. Res. Lett.*; see also Field and Heymsfield (2015), *Geophys. Res. Lett.*

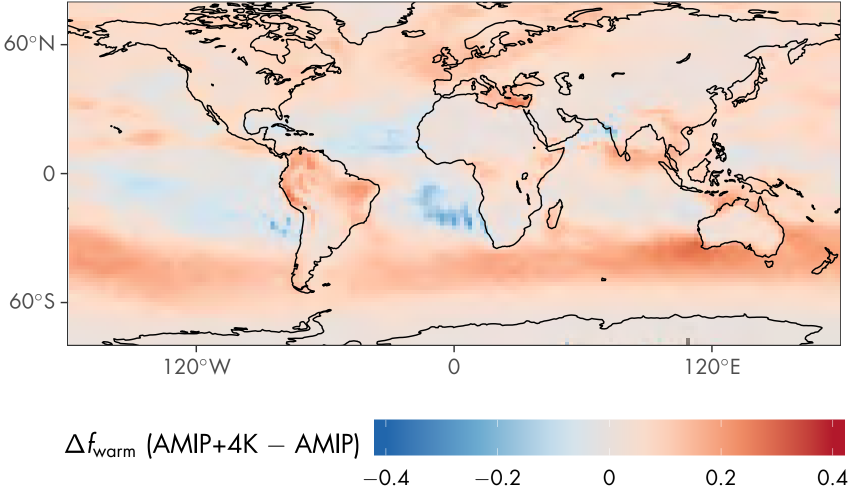
Modeled warm rain fraction is diverse



Warm rain fraction in ECHAM–HAM AMIP



In AMIP+4 K, the warm rain fraction increases, particularly in the SH midlatitudes



Warm rain leads to longer cloud condensate lifetime

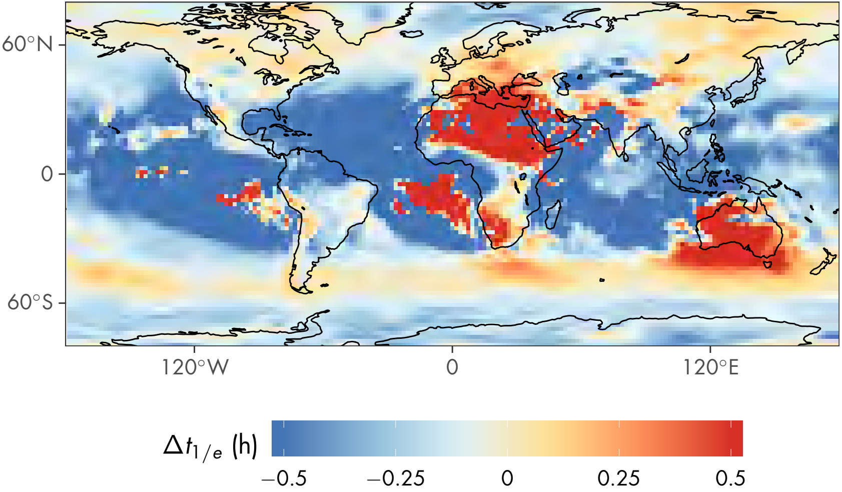
For a first-order process given by

$$P = -\frac{\partial(\mathcal{L}+\mathcal{I})}{\partial t} = \xi(\mathcal{L}+\mathcal{I}) \tag{2}$$

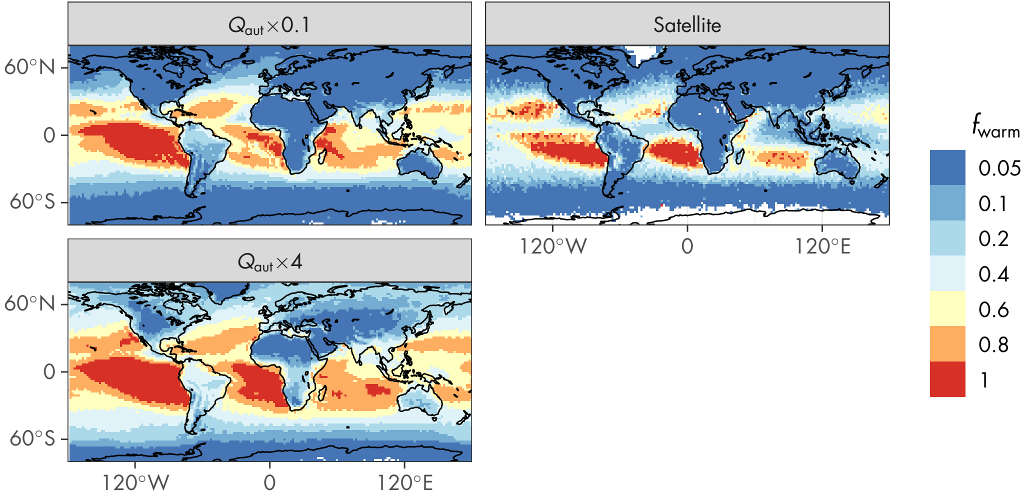
(with P the precipitation rate, $\mathcal{L}$ the liquid water path, and $\mathcal{I}$ the ice water path), we can define a "condensate lifetime" as the e-folding time constant ξ of the sink process. The lifetime can then be diagnosed from the model output:

$$t_{1/e} = \frac{\mathcal{L}+\mathcal{I}}{P} = \xi \tag{3}$$

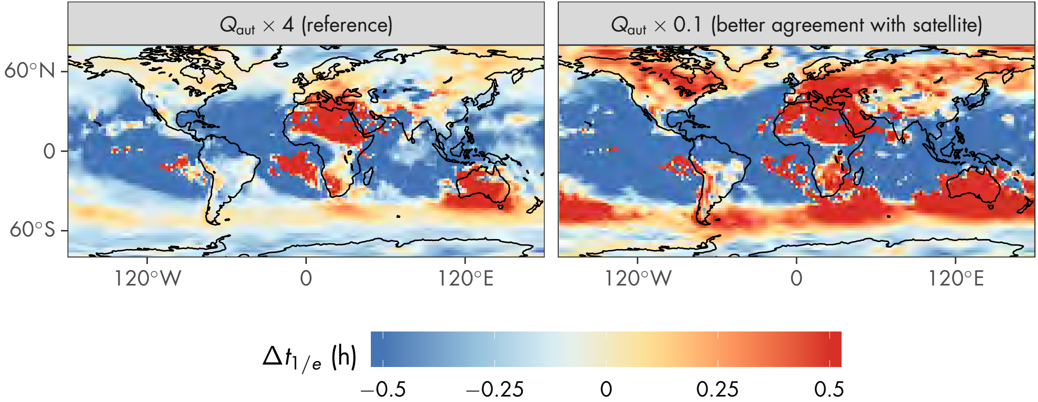
Estimate of condensate lifetime increase $\Delta t_{1/e}$ under 4 K SST increase



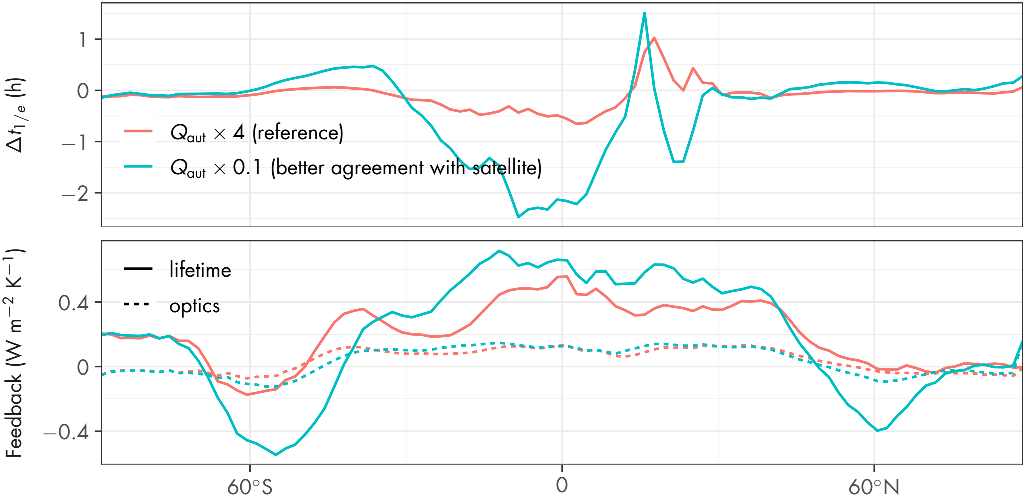
Warm clouds are too rainy in models (but scaling down autoconversion reduces the bias)



As a result, models underestimate the magnitude of the lifetime increase



Quantification of feedbacks: PRP on cloud phase and cloud condensate



Conclusions

- Warm precip efficiency is too high in GCMs; therefore, they underestimate the lifetime feedback in midlatitude clouds

- Use more process-oriented observational constraints